RESEARCH DEPARTMENT

# The measurement of sound insulation in the presence of flanking paths

RESEARCH REPORT No. PH-9

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THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

RESEARCH DEPARTMENT

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# THE MEASUREMENT OF SOUND INSULATION IN THE PRESENCE OF FLANKING PATHS

SUMMARY

*It is on occasions of advantage to determine the sound insulating properties of a partition material from a small sample or to measure the sound transmission through a new form of construction before the building of which it is part is complete. Under these conditions conventional sound insulation measurements are not possible and specialized techniques have been employed to obtain results. The predictions made by these techniques have been found to agree well among themselves, with theoretical results, and with conventional measurements where these have later been possible. The limitations of the methods are mentioned.*

## 1. INTRODUCTION

Many occasions arise in which it is of advantage to determine the sound insulating properties (a) of a partition material from a relatively small area or (b) of a particular construction before the building of which it is part has been completed. In the former case, if the sample is clamped into an opening for conventional measurements the results will be influenced by edge effects, and it is possible that an improvement may result from using relatively light supports for the edges of the partition and not attempting to prevent leakage of energy around the partition. In the second case, doors, windows, loading bays and similar openings in a building are not normally completed until a late stage in the construction with the consequence that faults, if they exist, cannot be rectified at the most convenient time. In such cases, the energy detected by a microphone on the side of a partition distant from a source of sound will consist principally of energy which has arrived by paths other than that through the material in which we are interested. Such paths of lower sound insulation are said to flank the construction under consideration and the term "flanking path", as in the title of this report, is used in this sense.

Even in completed buildings, it is, of course, obvious that the sound reduction between two areas is largely determined by the paths of lowest sound insulation, and an improvement will result if the insulation of such paths is increased. It is necessary, before steps can be taken to effect an improvement, to identify which parts of the structure are satisfactory in design and performance and which parts provide inadequate sound insulation.

A separation of a signal into its component parts may be accomplished on the basis of the time taken for the signal to traverse a particular path and two methods relying on such time discrimination will be described. A further method which has proved of value in several recent investigations enables a prediction to be made of the sound levels which would arise from measured vibration levels on the appropriate parts of the structure. An additional method depends on the production of a sound field having a high level within a confined area.

## 2. THE MEASUREMENT OF SOUND INSULATION

### 2.1. Measurements in the Laboratory and in the Field

In laboratory measurements of the airborne sound reduction index of a sheet of material[1] the test specimen is inserted in an opening between two reverberant rooms. The construction of these rooms is such as to reduce to a minimum the sound transmitted by any path other than that through the test specimen. A diffuse sound field is generated in the source room and since the receiving room is also reverberant, an approximation to a diffuse field will exist there also. The sound pressure level in both source and receiving rooms is determined by measurements taken with an omni-directional microphone at at least 5 positions in each room. The equivalent sound pressure level, $L$, is defined as 10 times the logarithm to base 10 of the ratio of the average throughout the room of the mean square sound pressure to the square of the reference pressure. Thus:

$$L = 10 \log_{10} \frac{p_1^2 + p_2^2 + \ldots\ldots p_n^2}{n.\ p_0^2} \text{ dB} \qquad (1)$$

where $p_1, p_2 \ldots\ldots p_n$ are sound pressures measured at positions 1, 2 ..... $n$.

$p_0$ is the reference sound pressure

The sound pressure level difference, $D$, is defined as the difference between the equivalent sound pressure level in the source room and that in the receiving room and we may write:

$$D = L_1 - L_2 \qquad (2)$$

where $L_1$ is the equivalent sound pressure level in the source room and $L_2$ is the equivalent sound pressure level in the receiving room.

The sound reduction index at a given frequency has a characteristic value for a given partition and is derived from the sound level difference by applying a correction which takes account of the area of the test specimen and the absorption in the receiving room. It is obtained from the equation

$$R = L_1 - L_2 + 10 \log_{10}(S/A) \qquad (3)$$

where $R$ is the sound reduction index, $A$ is the total absorption in the receiving room and $S$ is the area of the test specimen.

In field measurements, as opposed to laboratory measurements, it is not possible to determine a sound reduction index for any part of the construction since the measured values arise from transmission along many different paths. However, a value of the sound level difference (as opposed to the sound reduction index) between two rooms can be determined and this may be normalised, if required, to give the level difference corresponding to a reference value of the total absorption in the receiving room.

### 2.2. Recognition of the Problem of Flanking Paths

The existence of a flanking path may be suspected during the course of the measurements from the apparent direction from which the sound in the receiving room is arriving. Aural judgement of the direction is easier in acoustically dead enclosures, among which we may class many broadcasting studios, where the ratio of direct to reverberant sound is high. Such estimates will normally be supplemented by listening at different points in the receiving room. However, the importance of very small holes in the transmission of energy should not be over-emphasized.

A second indication of the presence of flanking paths will be found when the values of sound level difference are plotted as a function of frequency. For a simple construction which behaves as a pure mass, the sound level difference would theoretically continue to rise at approximately 6 dB/octave up to high frequencies, but in practice a slope of 5 dB/octave is more commonly found due to the presence of stiffness effects. More complex structures consisting of two or more leaves should show a greater slope and would equally be expected to show a curve rising towards the high frequencies.

Exceptions to this generalization exist, particularly those arising from resonant excitation of bending waves in the material by sound waves traversing the surface. If the velocity of propagation of incident plane waves is $v_0$ and the angle of incidence is $\theta$, then the velocity of the incident sound measured along the surface of the sheet is $v_0$ cosec $\theta$. Let the velocity of bending waves in the sheet be $v(f)$ (a function of frequency). Then at a frequency for which

$$v(f) = v_0 \operatorname{cosec} \theta \qquad (4)$$

the incident waves and the bending waves will remain in phase all over the sheet and maximum energy transfer will result. This effect is referred to as a "coincidence effect" because the two velocities in the plane of the sheet coincide. At grazing incidence cosec $\theta = 1$ and $v(f)$ is a minimum and equal to $v_0$. The frequency $f$ at which this occurs is known as the critical frequency. The effect may generally be recognized as a flattening or dip in the curve when the sound level difference is plotted against frequency, followed by a steeper portion of the curve. Curve ($a$) in Fig. 1 shows values for a theoretical mass-law construction while curve ($b$) is for a partition in which the critical frequency is at 2 kHz.

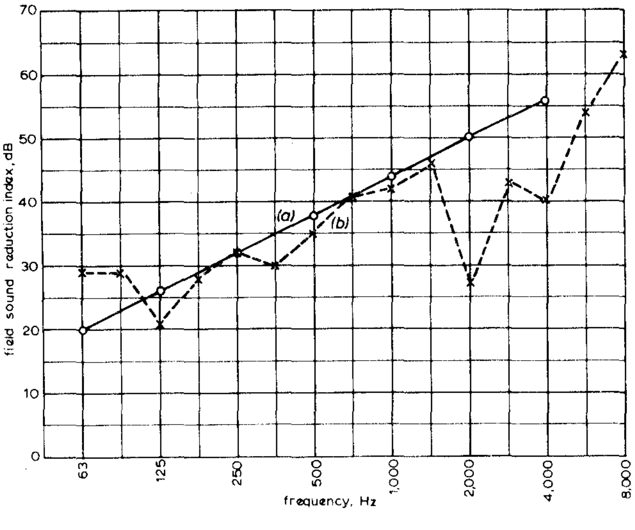


*Fig. 1 - Field sound reduction indices*

($a$) Based on mass law for 32·3 kg/m$^2$

($b$) Measured results showing coincidence effect

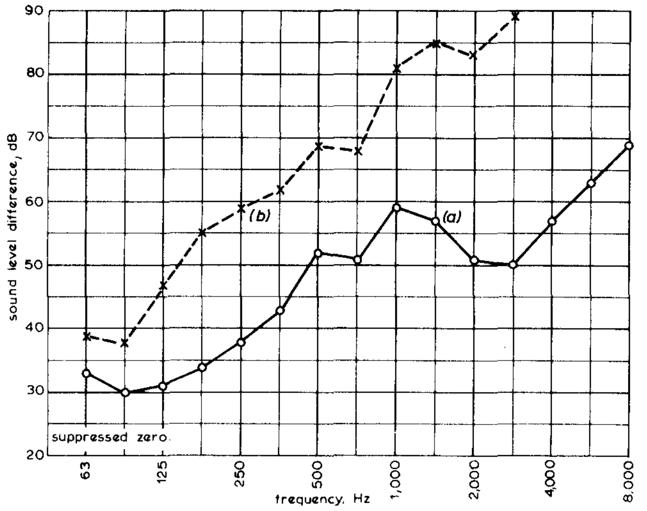


*Fig. 2 • Sound level differences*

(*a*) With flanking paths and coincidence effects
(*b*) After reduction of flanking paths and coincidence effects

The effect of a flanking path is normally to reduce the sound level difference generally and to flatten the curve towards some limiting value which depends on the properties of the flanking path. A typical measured curve showing the effect of such a flanking path is shown as curve (*a*) in Fig. 2. In this particular case the elimination of the flanking paths and a coincidence effect produced the results shown as curve (*b*).

Kodaras and Hansen[2] have used the results obtained by the close microphone method proposed by London[3] (which is described more fully in Section 3.4) to enable the presence of a flanking path to be recognized. Measurements made by the British Standard field method[1] using microphone positions distributed throughout the volume of the receiving room are compared with measurements taken on the receiving side very close to the face of the surface under test. An empirical correction is applied to the sound level difference values derived by these measurements and if the results are 3 dB or more higher at any frequency than those obtained by the "field" method, a flanking path would be expected. A similar difference found by any of the measurements described in the following Section will also indicate the presence of a flanking path.

## 3. MEASUREMENTS IN THE PRESENCE OF FLANKING PATHS

### 3.1. Correlation Measurements

The derivation of the cross-correlation function of a noise signal by analogue means was proposed in 1955 by Goff[4,5] for applications in many acoustic measurements, and as its use in the BBC Research Department has been described elsewhere[6] only a brief outline will be given here.

A random noise signal $f_1(t)$ is radiated by a loudspeaker in the source room and a microphone in the receiving room picks up $f_2(t)$, the combination of signals arriving by a multiplicity of paths. The correlation method depends on the derivation by analogue means of the cross-correlation function $\phi_{21}(\tau)$ which is defined by the equation

$$\phi_{21}(\tau) = \lim_{T \to \infty} \frac{1}{T} \int_0^T f_1(t)\, f_2(t-\tau)\, dt \qquad (5)$$

where $T$ is the integrating time of the equipment which should be long compared with the period of the sound of lowest frequency, and $\tau$ is a variable delay time.

The microphone output and the delayed noise signal are multiplied together and integrated by means of a pulse-height/pulse-ratio multiplier based on the work of Barber[7]. The output is plotted as a function of the applied delay time. We can therefore detect individual paths between the loudspeaker and microphone, each of which paths has a transit time corresponding to that of a maximum in the cross-correlation function.

Fig. 3 shows a pair of traces obtained from the correlation equipment, using octave-bands of white noise. Fig. 3(*a*) is that taken with the microphone on the source side of a partition; the direct and reflected sound may be seen as two groups of peaks having different delay times. Fig. 3(*b*) shows the corresponding trace with the microphone on the remote side of the partition and the sound transmitted directly through the partition is now separated from that travelling by other paths having longer transit times.

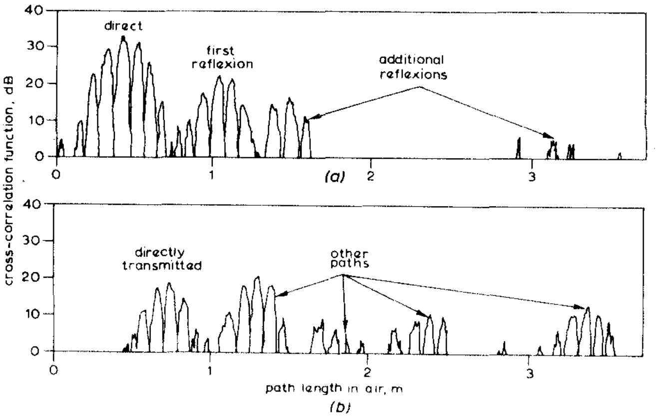


*Fig. 3 • Correlation traces for octave band noise*

(*a*) Source side showing correlation peaks from direct and reflected sound
(*b*) Receiving side showing the effect of several transmission paths

There are limitations in the use of this method. It is normally desirable to know the effect of frequency on the sound transmission and the bandwidth of the noise must therefore be limited by means of filters. This causes the single peaks in the cross-correlation function to be replaced by groups of peaks extending over a delay time interval inversely proportional jointly to the bandwidth and the centre frequency. Thus a limit is set to the time difference between paths which can be separated for a given frequency and bandwidth, and hence to the minimum size of sample or the closest approach to a flanking path which can be allowed. For octave bandwidths of sound, results can be obtained at and above frequencies for which the wavelength of sound in air is half the minimum dimension of the panel being measured; only above this frequency is it possible to separate sound transmitted through the material from that which has passed round the edges or through the flanking path.

Since the amplitude of the noise signal is, on the average, constant, the height of the greatest peak corresponding to a given path is proportional to the average pressure (if we are using a pressure microphone) of the signal arriving by that particular path. A value of the sound level difference for a given path can therefore be derived from the heights of the appropriate groups of peaks. The technique therefore isolates a particular direction of propagation from a reverberant-sound field. Since the sound level difference is normally a function of the direction from which the energy is incident it is ideally necessary to carry out measurements at many angles of incidence and integrate the total energy transmitted. The variation of sound level difference with direction will show the existence and frequency of any coincidence effects which may exist.

In order to get the best possible discrimination between direct and flanking paths the loudspeaker source and the microphone are operated as close to the surface under consideration as is convenient. This implies when the microphone is on the same side as the loudspeaker that the direct sound and that reflected from the surface will be seen as separate groups of peaks only at high frequencies. It is also necessary to consider the fall of sound pressure due to divergence of the sound field, since the distance between microphone and partition is usually comparable with the distance from the source. A correction can be determined for these two effects by moving the equipment to a free field and measuring the pressure drop between the microphone position used and the position of the panel.

Pressure on studio booking time and the physical size of the correlation analysis equipment render it impossible for measurements to be made in the field. Instead, a twin-track tape recorder may be used to record the signals for subsequent analysis. The phase relationship between the two channels has been found to be maintained to an adequate degree between recording and replay. A loop recording of duration greater than the integrating time of the equipment is replayed continuously and the two signals are multiplied continuously and integrated as already described.

### 3.2. Short-pulse Measurements

A method has been proposed by Raes[8] in which a short pulse of tone is radiated by a loudspeaker and picked up by microphones on each side of the partition. The signals, suitably amplified, are exhibited on an oscilloscope and the amplitudes of the pulses arriving at different transit times are measured from photographs of the traces such as are shown in Fig. 4. This method has very similar limitations to those of the correlation method. The length of pulse is equivalent to the bandwidth of the signal for correlation. It therefore has the same ability to separate paths of different lengths in the absence of extraneous noise. The signal-to-noise ratio obtainable with the short-pulse method is, however, considerably inferior to that from correlation. As for correlation measurements are taken for a specified direction and in the near-field of the loudspeaker.

The short-pulse method has the advantage that the results can be evaluated immediately whereas correlation analysis has to be carried out in the laboratory from recordings. Field measurements by this method are greatly simplified by the use of a camera capable of giving finished prints within a few seconds of taking the photograph.

### 3.3. Accelerometer Measurements

It has been shown by measurements in Research Department[9] that an estimate of the sound pressure level produced by radiation from a surface can be obtained by measurements of the vibration amplitude of the surface in question.

The sound pressure level is calculated by assuming that the surface has a radiation factor of unity, which is equivalent to assuming that the vibration of the panel is co-phased. Thus, if measurements are made of the vibration amplitude of the surface in which we are interested, it is possible to compute the sound pressure level in the enclosure which would arise if only this surface transmitted the energy. The reverberant-field sound pressure level is calculated and the results obtained by subtracting these values from conventional airborne sound pressure measurements in the source room.

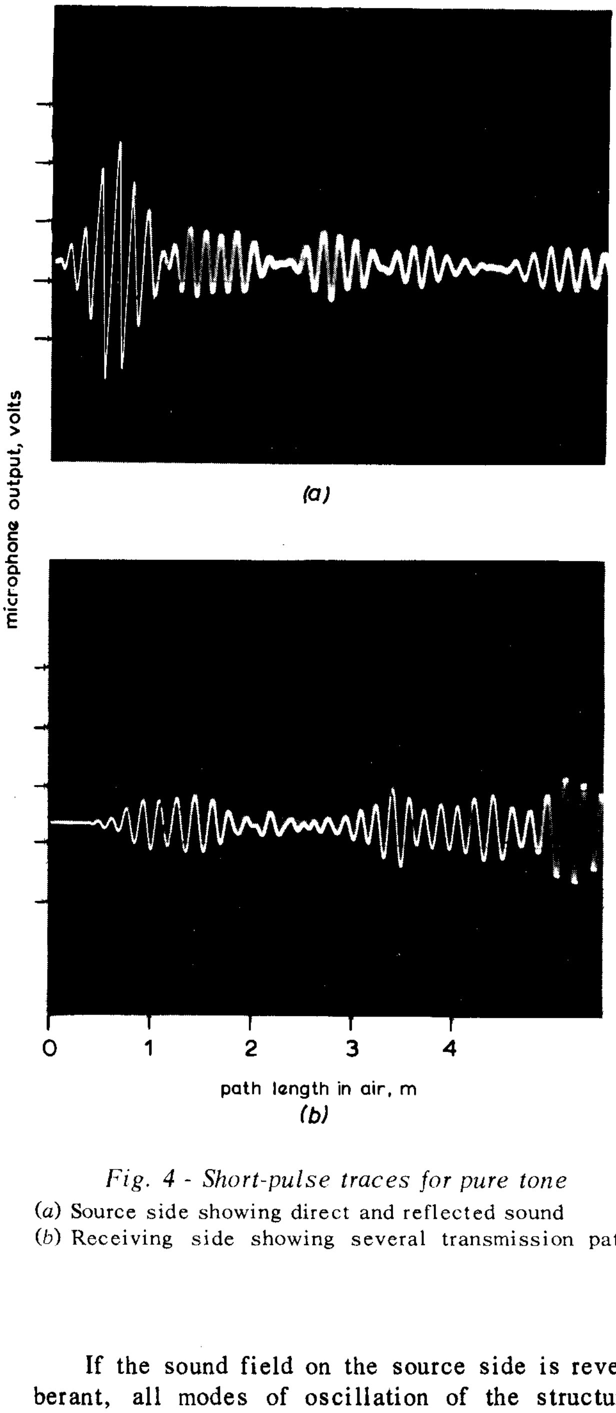


*Fig. 4 - Short-pulse traces for pure tone*
(*a*) Source side showing direct and reflected sound
(*b*) Receiving side showing several transmission paths

If the sound field on the source side is reverberant, all modes of oscillation of the structure will be excited and the results will be comparable with other measurements of the reverberant sound level difference.

For accurate results many accelerometer positions are required particularly at low frequencies. A practical compromise of five positions appears to give adequate results in most cases.

### 3.4. "London" Method Measurements

Two possible methods for the field measurement of transmission loss irrespective of flanking transmission have been proposed by London[2]. The first uses pressure microphones as in the laboratory measurements but in positions as close to the surface in the receiving room as is possible without touching. Three equations which cover different frequency regions were derived to give corrections for the partition area and receiving room absorption; these are applied to the measured sound level differences. If the sound field in the source room is not diffuse, close microphone positions may be used here in addition and a correction of 2·5 dB subtracted from the results at all frequencies.

As an alternative a velocity microphone (pressure gradient) has been employed and London developed a special form of such a microphone which permitted a very close approach to the surface under consideration. This is equivalent to the accelerometer method described above since the microphone enables the vibration velocity of the surface to be measured. An empirical correction is applied to the measured sound level differences. Close agreement has been reported between field measurements carried out in this way and laboratory measurements on similar partitions.

### 3.5. Other Measurements

Measurements have been made in certain limited cases by the use of an 0·45 in. (11·5 mm) calibre blank cartridge revolver which is fired close to the structure whose sound insulation is required. A very high level of sound is produced close to the structure being measured, and provided the flanking paths introduce large losses of energy due to diffraction round obstacles, it is possible in most cases to determine the sound level difference of the structure alone. The presence of reflecting surfaces such as adjacent buildings or even trees may easily introduce other flanking paths, and the method has proved of use only in limited cases.

In order to simplify the experimental arrangements, microphones are arranged on both sides of the structure and connected to a twin-track tape recorder. The microphone positions normally remain fixed but the revolver is fired from several different positions. The analysis of the recordings must be carried out by means of a peak reading instrument. An oscilloscope has been used for some measurements and an alternative method employing a peak reading programme meter with a rise time of 3 ms has been shown to introduce only a small error.

## 4. RESULTS OF TYPICAL MEASUREMENTS

### 4.1. Sound Insulation of a Steel Sheet

These measurements were carried out under

laboratory conditions and therefore permit the greatest number of comparisons between methods. A steel sheet of thickness 1·9 mm coated with a high-loss panel damping material to damp out resonances was mounted in the doorway of a reverberation room of volume 108 $m^3$. The surface density of this sheet is 17 $kg/m^2$. The sound field in this, the source room, was an approximation to a diffuse field at most frequencies. The doorway opened into a small corridor and staircase having a volume of 16 $m^3$ and a reverberation time of approximately 1 sec at mid-frequencies. The sample size and receiving room volume are below those recommended for transmission laboratories but comparative measurements on lightweight materials at middle and high frequencies are valid. Measurements on a given material using each room in turn as a source room are found to agree closely.

The mounted sheet is set some 600 mm behind the plane of the source room wall and the incident sound field cannot be completely random under these conditions. Correlation and short-pulse measurements were complicated by the presence of short-path reflections from the sides of this doorway which passed through the sheet with lower losses than the sound incident normally upon the surface.

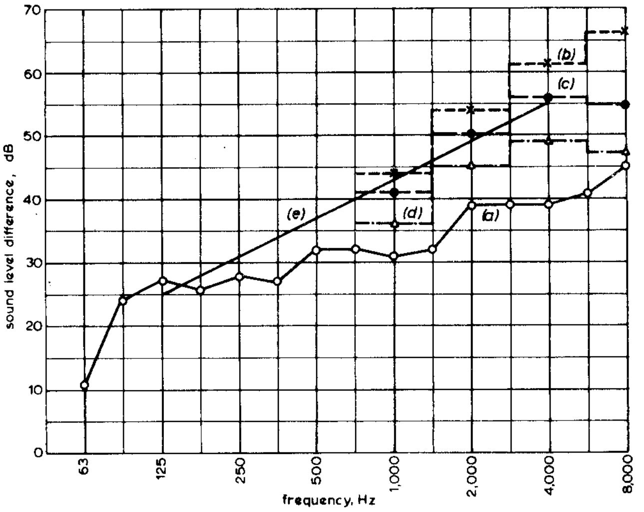


*Fig. 5 - Sound level difference measurements on a steel sheet*

(*a*) Reverberant-field sound pressure measurements
(*b*) Correlation measurements - normal incidence
(*c*) Correlation measurements - 45° angle of incidence
(*d*) Correlation measurements - 80° angle of incidence
(*e*) Mass-law curve for 17 $kg/m^2$ - normal incidence

Fig. 5 shows measurements of the sound level differences made under the above conditions. Curve (*a*) refers to reverberant field measurements made with warble tone; the reverberation room is the source room. The results show a degree of flattening above say 500 Hz and suggest that flanking paths exist in spite of efforts to seal the joints around the edges of the sheet. Curves (*b*), (*c*) and (*d*) are correlation measurements at 0°, 45° and approximately 80° angles of incidence. They show the reducing values of sound level difference as the angle of incidence increases, as are predicted theoretically. There is also greater loss in the octave centred on 8 kHz than in the other octaves, which is consistent with the existence of a coincidence effect. The calculated critical frequency for the steel sheet alone would be 6 kHz.

The results are somewhat higher than the reverberant field measurements and a single correlation measurement at 4 kHz for a wide range of delay times confirmed the existence of a number of paths.

Curve (*e*) in Fig. 5 is a mass-law (see Section 2.2.) curve as given by Beranek(10) for sound at normal incidence on a 17 $kg/m^2$ lamina. The correlation measurements at normal incidence lie somewhat higher than this curve due to the positioning of the loudspeaker so close to the panel that the measurements are carried out in a divergent sound field; no correction has been applied for the resultant fall of pressure with distance.

Fig. 6 shows short-pulse measurements at 0° and 60° angle of incidence compared with the same mass-law normal-incidence curve. The results show agreement in general terms with the previous correlation measurements and once again are slightly in excess of the mass-law values. Curve (*a*) in Fig. 7 shows results calculated from accelerometer measurements on the same steel sheet. The sound field in the source room was reverberant but, as explained above, the waves incident upon the steel sheet were limited to angles of incidence not greater than 45° with consequently only a slight reduction below normal incidence theoretical values (curve (*b*)). The results agree well with the mass-law values between 250 Hz and 2 kHz. Above this frequency the fall below the mass-law values is due to the presence of a coincidence effect. The reverberant field pressure measurements are plotted again as curve (*c*) to illustrate the effects of leakage around the edge of the sheet.

### 4.2. Sound Insulation of a Television Interview Studio

Sound insulation measurements have been made in a temporary television interview studio constructed of prefabricated panels in a girder framework. The sections are of an interlocking wood frame clad on each face with asbestos cement sheets and the cavity filled with a cement loaded wood fibre. Many of the sheets were found to be inadequately filled with cement and since this would affect the fire rating given to the completed structure those which sounded hollow had been opened and packed with additional cement.

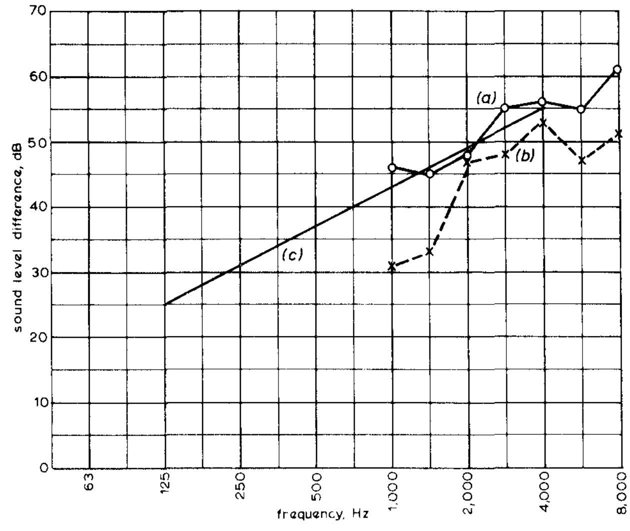


*Fig. 6 - Sound level difference measurements on a steel sheet*

(*a*) Short pulses - normal incidence
(*b*) Short pulses - 60° angle of incidence
(*c*) Mass-law curve for 17 kg/m$^2$- normal incidence

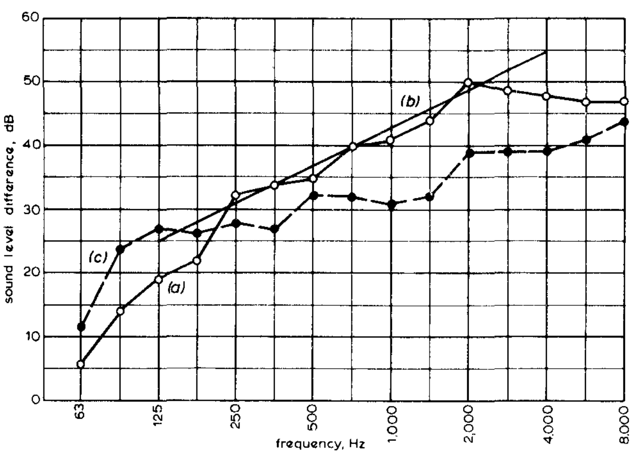


*Fig. 7 - Sound level difference measurements on a steel sheet*

(*a*) Calculation based on accelerometer measurements
(*b*) Mass-law curve for 17 kg/m$^2$ - normal incidence
(*c*) Reverberant field pressure measurements

Research Department was asked to determine the sound insulation of the walls before the scenery doors or any of the windows were in position. The results of measurements are shown in Fig. 8. Curve (*a*) was derived from accelerometer measurements and (*b*) from correlation measurements at normal incidence. The excess of the correlation measurements over accelerometer measurements at mid frequencies probably arose from the restriction to normal incidence in the correlation measurements. It was apparent from listening on the outside of the structure and confirmed by the correlation measurements that the joints between the panels were not sealed. On the basis of these considerations it was predicted that the overall mean insulation of the completed structure would be of the order of 32 dB.

Airborne sound insulation measurements were made at a later stage when doors and windows had been fitted and the results are shown as curve (*c*) in Fig. 8. The mean value (125 Hz - 2·8 kHz) is 36 dB. The entire outside surface had been sprayed with a granite chipping fire protection coating which had sealed all the cracks and this undoubtedly led to an improvement in the airborne insulation.

The results, however, were generally below those which might be expected of a lamina of this weight (curve (*e*) in Fig. 8) and the accelerometer measurements were repeated. The results shown as curve (*d*) agree more closely with the expected values. Since it is unlikely that the addition of granite chippings could have caused this difference it seems probable that insufficient accelerometer positions were measured on the first occasion to sample a representative number of the prefabricated sections.

The airborne measurements show the existence of a flanking path and this will probably be through the roof which is of a lightweight construction.

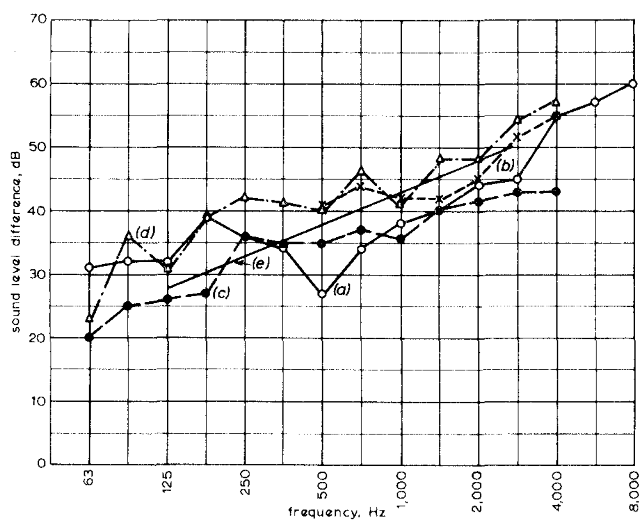


*Fig. 8 - Sound level differences for a studio wall*

(*a*) Calculation based on accelerometer measurements
(*b*) Correlation measurements
(*c*) Reverberant field pressure measurements
(*d*) Repeat of accelerometer measurements
(*e*) Practical random incidence results for a 59 kg/m$^2$ lamina

### 4.3. Sound Insulation of a Television Studio Roof

Much thought has been given recently to the design of roof structures adequate to protect programmes from interference by aircraft noise. Noise measurements at one site in Scotland where landing aircraft pass overhead at a height of approximately 300 m, taken in conjunction with an estimate of possible future increases of noise level, led to the

specification of a roof having an average insulation of 70 dB. Such an insulation must be obtained from a double skin construction and in this case each skin was of 150 mm concrete. For reasons unconnected with sound insulation the airspace between the skins was made approximately 1·5 m deep.

Specifications for the construction of other studio roofs were required before the completion of this studio and measurements had to be made before the doors were fitted. Aircraft noise could not be used since the paths through the large scenery doors flanked the roof construction. Successful measurements were made with a revolver because owing to the proximity of the source to the roof, the flanking paths at ground level did not assume any importance. Fig. 9(*a*) shows the measured values obtained by this method and for comparison (*b*) shows the sum of individual measurements obtained on the two skins at a later date. It is assumed here that the depth of the air space is sufficient to reduce coupling between the two skins through the air space and the results largely confirm this assumption.

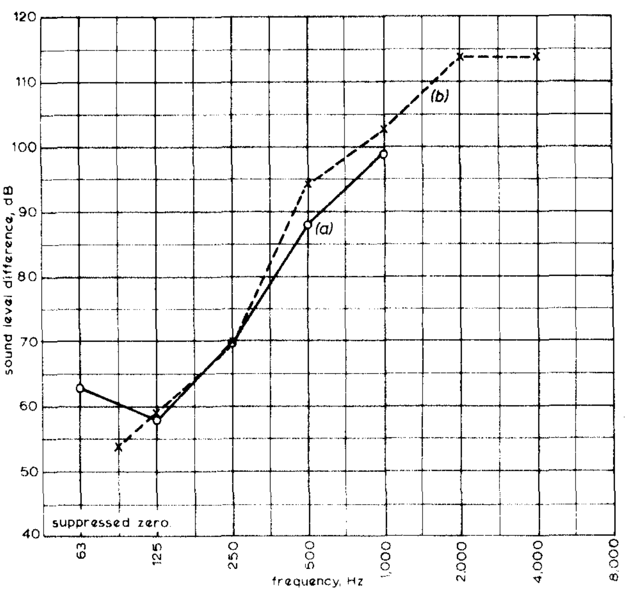


*Fig. 9 - Sound level differences for a television studio roof*

(*a*) Revolver shot measurements
(*b*) Sum of individual skin measurements

These results were considered at the time to be surprisingly high and additional measurements were subsequently undertaken to verify the results. Fig. 10(*a*) shows measurements between the studio and the airspace with warble tone emitted from two loudspeakers as source. Curves (*b*) and (*c*) are for the outer skin and were measured on revolver shots and aircraft noise respectively. The agreement between the two methods is extremely close and compare well with the measurements on the inner skin. Curve (*d*) shows the experimental results expected for a single skin of this weight; the critical frequency for coincidence effects in a concrete skin of this thickness would be at approximately 150 Hz and will account for the reduction of the measured values below theoretical values in this region.

## 4.4. Sound Insulation of a Free-Field Room

A new free-field room (Sound Measurement Room No. 2) has been constructed at Kingswood Warren[11]. To provide quiet working conditions suitable for subjective tests or hearing threshold measurements, it was desirable that aircraft noise should be excluded, and a double skin roof having a 1·8 m air space was constructed. Measurements were made from the roof to both the airspace and the free-field room by revolver shots and from the airspace to the free-field room with a loudspeaker as source. The revolver shots were recorded with microphones on the roof, in the airspace and in the free-field room and were subsequently analysed through octave band-pass filters by a peak reading meter. The results obtained are shown in Fig. 11. Curves (*a*) and (*b*) are the sound level differences from the roof to the airspace and to the free-field room respectively. They are compatible with the known weight of the structures and will be adequate to exclude aircraft noise.

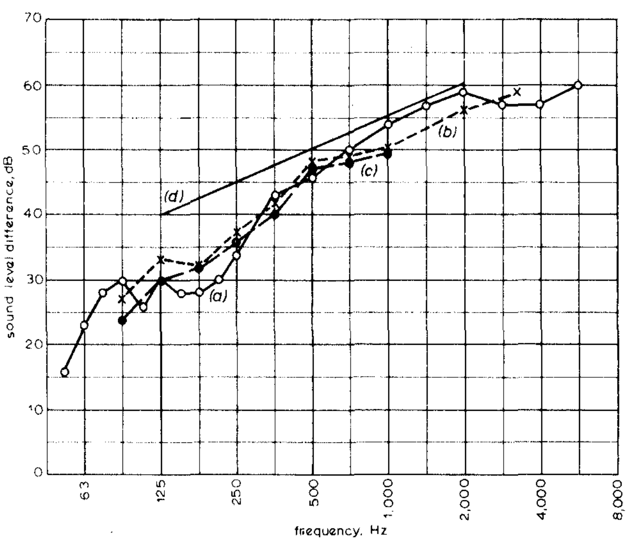


*Fig. 10 - Sound level differences across individual skins of a television studio roof*

(*a*) Loudspeaker and warble tone, inner skin
(*b*) Revolver measurements } outer skin
(*c*) Aircraft noise } outer skin
(*d*) Practical random incidence results for a 350 kg/m² lamina

Curve (*c*) shows the measured sound level difference from the airspace to the free-field room determined by the standard method for field measurements of airborne sound transmission. This curve

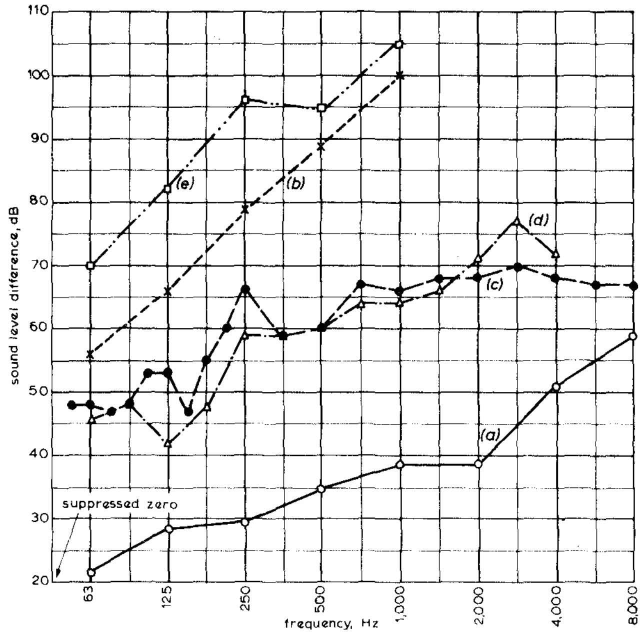


*Fig. 11 - Sound level differences for roof structure of a free-field room*

(*a*) Revolver shots measurements, open air to airspace
(*b*) Revolver shot measurements, open air to free-field room
(*c*) Loudspeaker and warble tone, airspace to free-field room
(*d*) Accelerometer measurements, airspace to free-field room
(*e*) Sum of individual skin measurements

would have been expected to rise very steeply due to the presence of foam wedges forming the sound-absorbing lining of the foam. Flanking paths existed at points where the lights are introduced to the room and additional lightly capped holes available for suspending experimental apparatus.

Curve (*d*) was obtained from airborne sound measurements in the source space together with vibration measurements on the floor of the airspace (the roof of the free-field room). The radiation has been assumed to be plane wave radiation into free space and no addition has been made for the presence of the absorbing wedges. It seems probable that the excess values of curve (*c*) over those of curve (*d*) in the region 90 - 120 Hz mark the beginning of the absorption of energy by the wedges and that the rise does not continue beyond 250 Hz because of the existence of the flanking paths.

The fall of curve (*d*) beyond 2·8 kHz is thought to be due to direct excitation of the accelerometer by the sound field since in this experiment the vibration measurements had to be made in the source room. In some cases it is an advantage not to have to reach the distant side of a partition which may be, for instance, an inaccessible roof. In such a case, provided only a single skin structure is involved, the accelerometer may be used on the source side, but the possibility of direct excitation of the accelerometer should be borne in mind.

Curve (*e*) is the sum of curves (*a*) and (*c*) and should be comparable with the direct measurement to the free-field room. The agreement is disappointing below 500 Hz and may point to the existence of a path through the apparatus room at ground floor level affecting the revolver shot measurements.

## 5. CONCLUSIONS

Several methods for the measurements of sound insulation in the presence of flanking paths have been described, some of which supply evidence to assist in the recognition of a flanking path if this is not obvious. Agreement between these specialized measurements and conventional reverberant field measurements in the absence of flanking paths is usually good, but it is advisable to carry out measurements by more than one technique and to examine critically the results obtained.

Correlation and short-pulse measurements are restricted to producing results corresponding to transmission along a straight line joining source and receiver. Full information on the behaviour of a partition requires several measurements at various angles of incidence. Additionally the results are valid only for a restricted area and if variations in the physical characteristics exist from point to point they can be fully explored only by a series of measurements.

A high signal-to-noise ratio is obtainable in correlation measurements and results can be obtained in the presence of a high level of extraneous noise. It is necessary, however, to record the information on site and process it on return to the laboratory. The recording of the information is comparatively simple and rapid and time in the studio is reduced to a minimum. Short-pulse measurements on the other hand do not have the same ability to reject extraneous noise and while an improvement in signal-to-noise ratio can be effected by the use of narrow-band filters together with long pulses there is a consequent reduction in discrimination between paths. The time required to make measurements is greater than with correlation but results are available immediately and this may enable further exploration to be undertaken and possibly reveal the position of the flanking path if this is unknown.

Accelerometer measurements can be made under conditions of random incidence and the results determined are directly comparable with reverberant field pressure measurements. However, once again the measurements refer to the points to which accelerometers are attached and a wide selection of points may be necessary to allow for variations in the partition construction. The derivation of the results normally takes too long to be conveniently carried out on site.

Revolver shots are invariably recorded and the analysis awaits return to the laboratory.

If the results of these measurements are to be used to predict the behaviour of a partition a physical examination must be made to determine the extent of any inevitable gaps or cracks and this information taken in conjunction with the measurements in arriving at a final result.

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